D Distributed Systems

D.1 Overview

- Definition and Motivation
- Taxonomy
- Communication Models
- Selected Problems of Distributed Systems
- Object-Based Distributed Systems

D.2 References

General:

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Special Problems:

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Flyn72. M. J. Flynn: “Some Computer Organizations and Their Effectiveness.” *IEEE Transactions on Computers*, **C-21**, Sept. 1992, pp. 948–960.

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D.3 Definition and Motivation

- ★ *"Distributed System"* My definition
  - ◆ Hardware and software of multiple cooperating computers
- *“Distributed System”*
  Definition according to Tanenbaum and van Renesse
  - ◆ It looks like an ordinary centralized system.
  - ◆ It runs on multiple, independent CPUs.
  - ◆ The use of multiple processors should be invisible (transparent).
- *“Distributed System”*
  Definition according to Mullender
  - ◆ Additionally: Not any single points of failures

1 Advantages

- Efficiency to cost ratio
  - ◆ High performance computers are very expensive
  - ◆ Microprocessors became very cheap
  - ◆ Multiple microprocessors can easily have more computing power than a high performance computer and cost much less.
- ★ Costs
  - ◆ Distributed systems can be much cheaper at same capacity.
  - ◆ Expensive devices (e.g., color printers) can be shared by many users.
- ★ Efficiency
  - ◆ Distributed systems can be much more efficient than any available high performance computer.

1 Advantages (2)

- Centralized CPU vs. personal computer
  - Response time of centralized systems is very bad at high load.
  - Personal computers are available for a single user.
  - More computing power available for a single user: better user interfaces, etc.
- Load Balancing
  - Unlike individual PCs, a distributed system can grant peak performance to a single user without annoying other users.
- Inherent distribution
  - People are distributed
  - Information is distributed
  - Devices are distributed
  - Distributed systems model the inherent distribution of today's organizations.
  - People can communicate via distributed systems. Some day, a distributed system might replace the POTS (plain old telephone system).

1 Advantages (3)

- Scalability
  - "No" restriction on the maximum size of the system.
- Extensibility, incremental growth
  - It is easier to add a new computer to a distributed system than to extend a high performance machine.

1 Advantages (4)

- Availability
  - Distributed systems can have redundant components (CPUs, memory, communication channels, etc.)
  - System just runs on if a component fails.
- Reliability
  - Reliability needs availability.
  - Reliable systems mask failures (e.g., CPU failure, communication failures, etc.)
  - Distributed systems can be made very reliable. However, this is a difficult task.

2 Disadvantages

- Concurrency
  - Distributed systems are inherently concurrent.
  - Controlling concurrency is complex.
  - Combining well-understood components can generate new problems not apparent to the components.
- Propagation of effect
  - One malfunctioning computer can bring down the whole system.
  - There can be unforeseen dependences between components.
- Security
  - It is harder to secure a physically distributed system.
  - Communication channels can be wire tapped and eavesdropped.
  - Data access could not be controlled on certain sites.

2 Disadvantages (2)

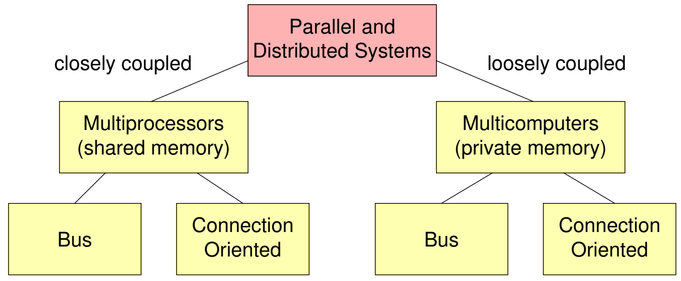
- Efficiency
  - Distributed systems can only gain efficiency for the total output of the entire system. If you cannot parallelize your application you cannot benefit from the available high performance.
- Load Balancing
  - It is hard to balance the load because the physical distribution of resources may not match the distribution of demands.
- Scalability
  - A working system with ten nodes may fail miserably when it grows to a hundred nodes.
- Complexity
  - All in all, a distributed system is much more complex than a centralized one (e.g., dealing with partial failures, concurrency, load balancing, etc.)

D.4 Taxonomy

- Classification according to Flynn (1972)
  - SISD – Single Instruction Stream, Single Data Stream
    all current single CPU computers (PCs, Mainframes)
  - SIMD – Single Instruction Stream, Multiple Data Streams
    high performance computers, vector computers
  - MISD – Multiple Instruction Streams, Single Data Stream
    no known system available that implements this category
  - MIMD – Multiple Instruction Streams, Multiple Data Streams
    systems with independent CPUs
- Distributed systems are always seen as MIMD computers

D.4 Taxonomy (2)

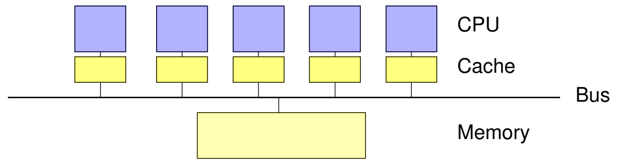
- Taxonomy of parallel and distributed computer systems (MIMD)



according to Tanenbaum 1995

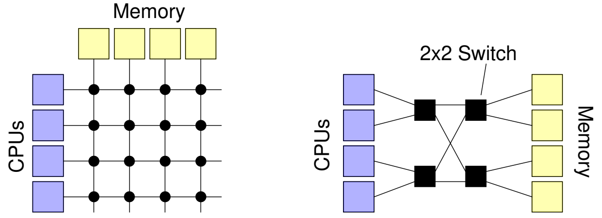
1 Multiprocessors

- Shared memory
  - All CPUs share the memory
  - Memory is coherent
    - Written data items are immediately visible to other CPUs
- Bus-based systems
  - CPUs access memory via a bus
  - Limited number of CPUs
  - Increased performance by CPU-side caches
  - Cache consistency achieved by bus snooping



1 Multiprocessors (2)

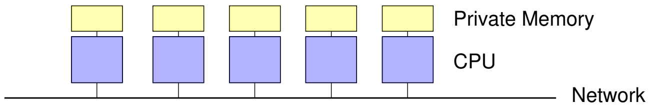
- Connection-oriented systems
  - For more than 64 processors bus-based systems fail
  - Cross-bar switch / Omega switching network



  - Cross-bar switches need n^2 switches
  - Omega networks need $n \cdot \log_2 n$ switches
  - Slow memory access
  - Solution: hierarchical systems (NUMA = Non uniform memory access)

2 Multicomputers

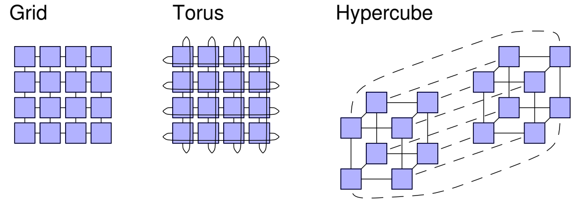
- Each CPU has its own private memory
- Bus-based multicomputers
  - Workstations in a LAN



  - CPUs connected to a fast communication bus

2 Multicomputers (2)

- Connection-oriented multicomputers
  - Examples of topologies:



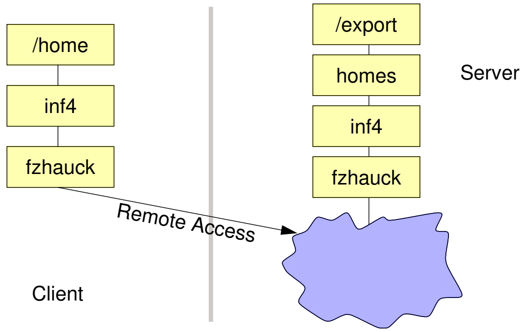
  - Each CPU is connected to a number of other CPUs
- Computers in a wide area network?
  - Bus-based, as each CPU is virtually connected to every other
  - Connection-oriented, as there is no uniform access to other CPUs

3 Network Operating Systems

- Early distributed systems
- Loosely-coupled systems
  - Multicomputers usually in a LAN
- One (but not necessarily the same) operating system on each system
  - Users act locally
  - Users have access to remote systems
    - Remote login: **`rlogin faui04a`**
    - Remote copy: **`rcp faui04a:aFile myCopy`**
    - Shared file systems
    - Shared devices (e.g., printers)

3 Network Operating Systems (2)

- Shared file systems
  - Users can operate on remote files as on local files
  - File server provide remote access to local files
  - Local file name is not necessarily equal to remote file name



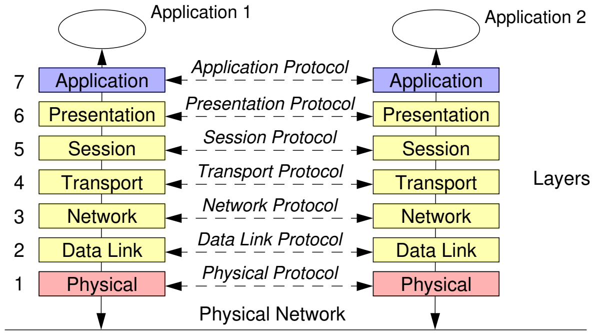
4 True Distributed Systems

- Same operating system on each node
- System behaves like a uniprocessor
  - Users should not see any differences
    if they access the system from another node.
  - The identity of the local computer is not important.
  - File sharing semantics is usually well-defined.
- Transparencies
  - Location transparency — location of resources is irrelevant
  - Migration transparency — resources may move
  - Replication transparency — resources may be replicated
  - Concurrency transparency — multiple accesses to a resource at a time
  - Parallelism transparency — activities may be executed in parallel

D.5 Communication Models

- Communication needs agreement
  - Protocols

1 Protocol layers according to the ISO OSI reference model



1 Protocol Layers (2)

- Physical Layer
  - Transmission of 0s and 1s on the wire
- Data Link Layer
  - Sending bits; separating frames or packets; checking frame integrity
- Network Layer
  - Routing of messages in larger networks
- Transport Layer
  - Implementation of reliable connections
  - Fragmentation and reassembling
- Session Layer
  - Dialog control; synchronization

1 Protocol Layers (3)

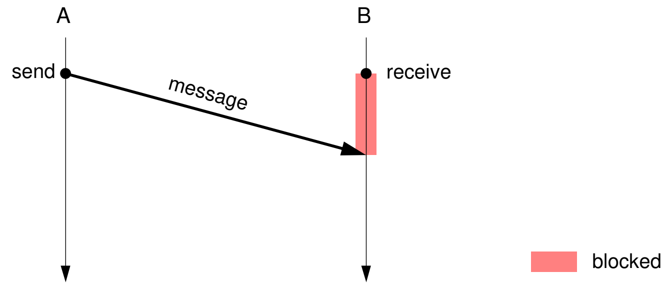
- Presentation Layer
  - ◆ Transparency of different internal representations of data
- Application Layer
  - ◆ Set of application protocols
    - Electronic mail protocol
    - File transfer protocol
    - etc.

2 Classification

- Synchronicity
  - ◆ Is the sender blocked until the receiver gets a message, or not?
- Pattern of Interaction
  - ◆ Message Passing — a message is sent from one party to the other
  - ◆ Request-Reply (Client-Server) Interaction —
    there is a message to the receiver and a message back to the original sender
- Addressees
  - ◆ One receiver
  - ◆ Multiple receivers (group communication, multicast, broadcast)

2 Datagram Message

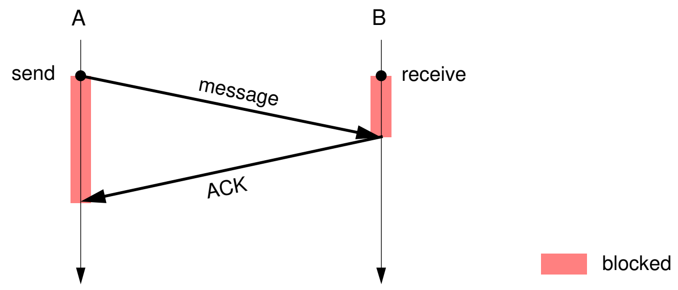
- Message passing; asynchronous send



  - ◆ Sender can proceed immediately
  - ◆ Receiver may be blocked until a message arrives
  - ◆ Needs buffer space for not yet received messages

3 Rendezvous Model

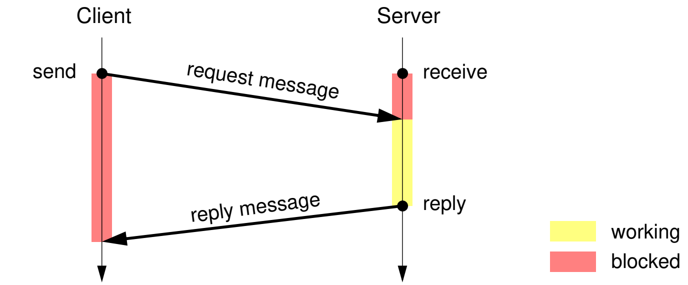
- Message passing; synchronous send



  - ◆ Sender waits until message is received
  - ◆ Receiver may be blocked until a message arrives
  - ◆ Needs no buffer space

4 Synchronous Request-Reply Model

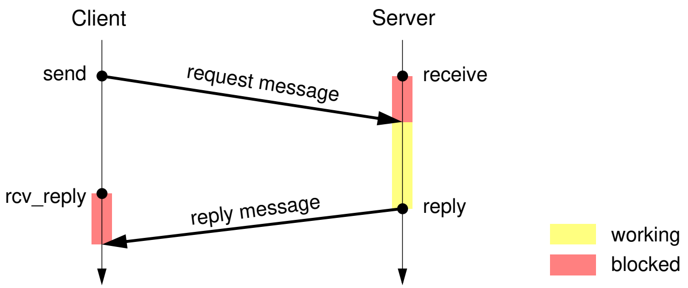
- Request-reply interaction; synchronous send



- ◆ Client waits until reply message is received
- ◆ Server may be blocked until a request message arrives
- ◆ Client and server do not work concurrently
- ◆ Well known representative is the RPC (remote procedure call)

5 Asynchronous Request-Reply Model

- Request-reply interaction; asynchronous send



- ◆ Client and server can work concurrently
- ◆ Basis for group communication

6 Reliability

- It is possible that messages get lost if we do not use a reliable connection
  - ◆ Reliable connections introduce acknowledge messages (ACK)
  - ◆ For simple message passing this means a lot of overhead

★ Combining reliability with the request-reply interaction model

- Possible errors
  - ◆ Server crash
    failure model is: total amnesia
    (server looses all knowledge of former requests)
  - ◆ Request message gets lost
  - ◆ Reply message gets lost
- Ideal semantics
  - ◆ *exactly-once*
    The request is processed exactly once at the server side.

6 Reliability (2)

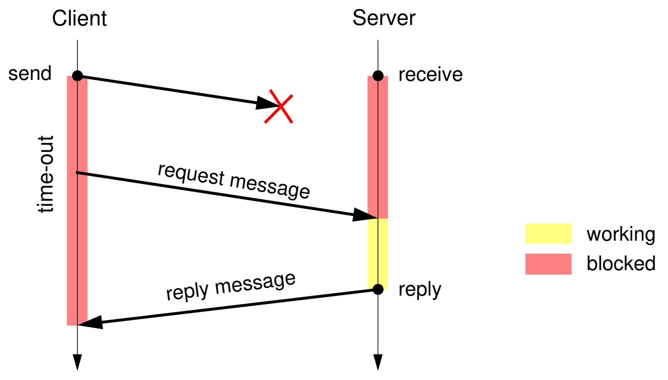
- **At-Least-Once Semantics**
  - ◆ Request is processed once or more times
  - ◆ Client will never notice an error message, but it may notice that the request was processed multiple times: operations need to be *idempotent*.
- Implementation
  - ◆ If the client does not get a reply message after some time (time-out), it resends the request.
    - There is no additional functionality needed at the server side.
    - However, the server can ignore resent requests if it can detect them.

6 Reliability (3)

- **At-Most-Once Semantics**
  - The request is processed once or not at all.
- Simple implementation (at the client side only)
  - If the reply message does not arrive within a certain period of time an error is returned to the caller (at-most-once semantics).
  - Otherwise, the result is returned (exactly-once semantics).
- More complex implementation
  - Client repeats request message after time-out (hides message losses on the wire).
  - Client has to identify server crashes (error code to the caller, at-most-once semantics).
  - Server keeps reply messages (enables resending if message gets lost)
  - Server has to identify and ignore old requests after server crash.
  - If the result is returned we have exactly-once semantics.

6 Reliability (4)

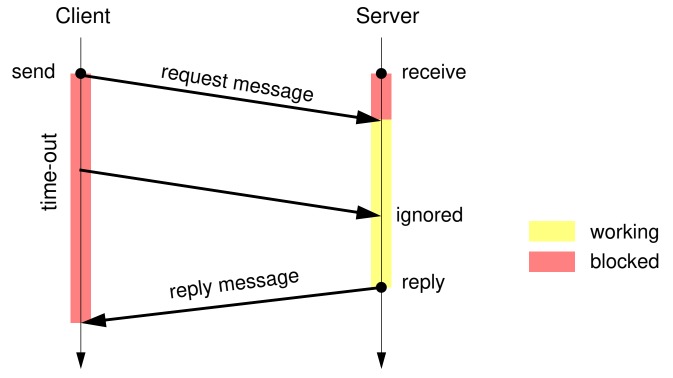
- Request message gets lost



- Request is repeated

6 Reliability (5)

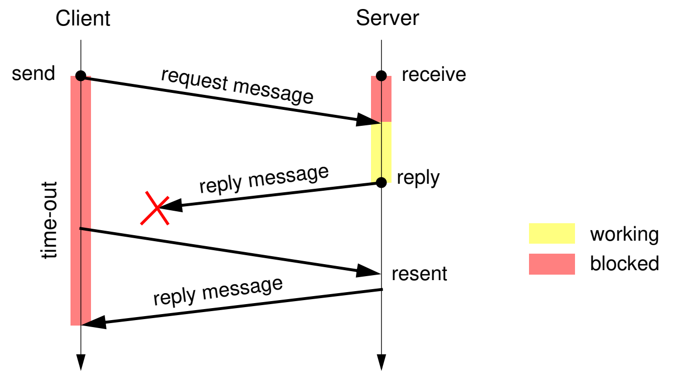
- Processing has not yet finished



- Repeated request is ignored

6 Reliability (6)

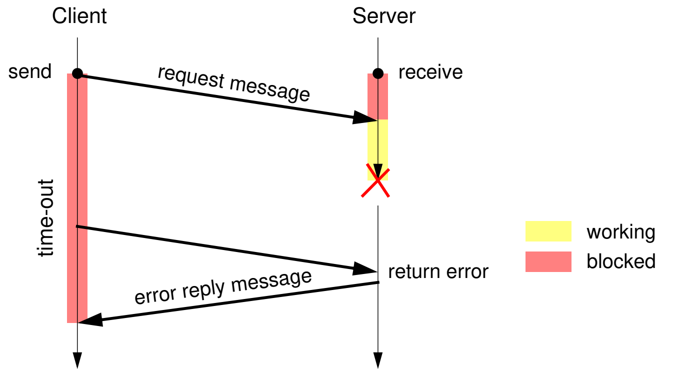
- Reply message gets lost



- Server keeps reply message and resends it

6 Reliability (7)

- Server crashes



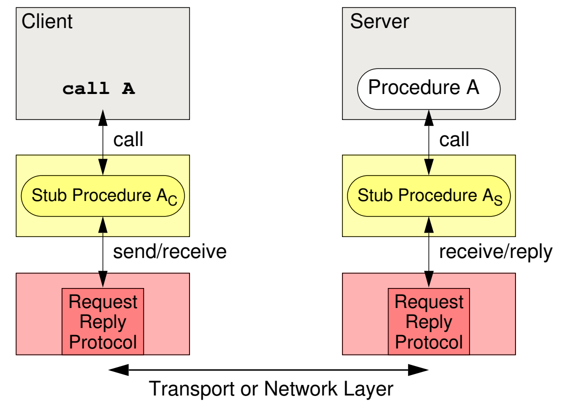
- ◆ Server identifies old requests (old generation number) and returns error code (at-most-once semantics)

7 Remote Procedure Calls

- Request-reply model can be used to implement RPCs [Birrell and Nelson 1984]
  - ◆ Instead of sending a request message, we invoke a remote procedure
  - ◆ Instead of receiving a reply message, we get the results of the invocation
- ★ Invocation of a procedure is location-transparent
  - ◆ Syntax may be the same for local or remote invocation
  - ◆ Very intuitive
  - ◆ No need for explicit usage of send and receive primitives
- Implementing RPCs
  - ◆ Stub procedures on client and server side

7 Remote Procedure Calls (2)

- Implementing RPCs using stub procedures



acc. to Nehmer 1995

7 Remote Procedure Calls (3)

- Client stub procedure
  - ◆ Marshalling of parameters (composing a request message)
  - ◆ Sending request message
  - ◆ Waiting for reply message
  - ◆ Unmarshalling of the result
  - ◆ Implementing delivery semantics
- Server stub procedure
  - ◆ Receiving request message
  - ◆ Unmarshalling of parameters
  - ◆ Invoking server procedure
  - ◆ Marshalling of the result
  - ◆ Sending reply message
  - ◆ Implementing delivery semantics

7 Remote Procedure Calls (4)

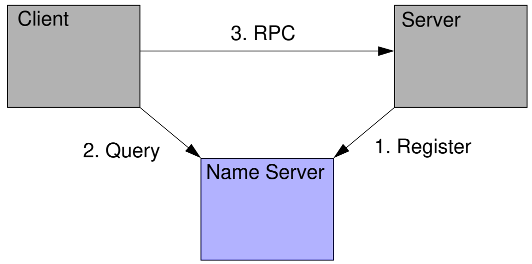
- Problems with RPCs
  - Marshalling of parameters
    - Number and types must be known
      (cmp. with C: `printf( "Count %d\n", count )`)
  - Parameter passing semantics
    - *Call-by-value:* no problem
    - *Call-by-reference:* How to implement?
  - No global variables
  - Semantics
    - Server crashes; no exactly-once semantics
  - Performance
    - No concurrency
    - Large parameter data
    - Short procedures

7 Remote Procedure Calls (5)

- Automatic generation of stub procedures
  - Tools generate code for:
    - parameter marshalling
    - client stub procedure
    - server stub procedure
    - server loop waiting for request messages
- Binding client stubs to server stubs
  - Server stub has a network address that must be known to the client stub
  - Problem: How does the client know its server?
- ★ Name server
  - Symbolic names are converted to network addresses

8 Name Server and Binding

- Well known name server converts names to addresses
  - Client knows a unique name for its server and the address of a name server
  - Name server converts this name to a dynamic network address
  - Client can always bind to the server
  - Server has to register its dynamic network address with the name server

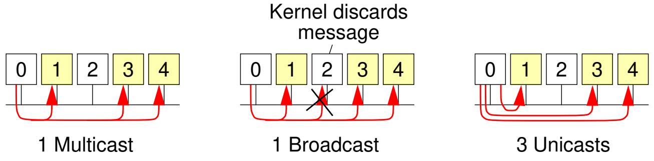


9 Group Communication

- Motivation
  - Often more than one server needs to be informed
    - multiple servers administrate a resource
    - multiple redundant servers (no “single point of failure”)
- Terminology
  - Unicast
    - One receiver (1:1)
  - Anycast
    - One receiver of many (1:1 of n)
  - Multicast
    - Multiple receivers (1:n)
  - Broadcast
    - All receivers of a special group (1:n)

9 Group Communication (2)

- Implementation of multicast
  - ◆ Using a hardware-based multicast
    - e.g., Ethernet multicast
  - ◆ Using a hardware-based broadcast
    - e.g., Ethernet broadcast
    - filtering of not addressed parties at receiver side
  - ◆ Using unicast messages
    - sending an individual message to each party



acc. to Tanenbaum 1995

9 Group Communication (3)

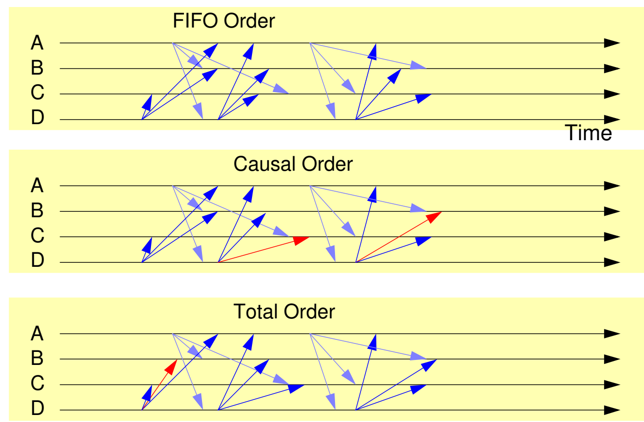
- Primitives for group communication
  - ◆ Message passing
    - Same primitives as for unicasts (`send`, `receive`) and multiple addressees for `send`
    - Different primitives: `group_send`, `group_receive`
  - ◆ Request-reply interaction
    - Multiple `rcv_reply` invocations to get all reply messages
- Variants of group communication semantics
  - ◆ *Reliability:* none, k-reliable, atomic/reliable
  - ◆ *Message ordering:* none, FIFO order, causal order, total order

9 Group Communication (4)

- Reliability
  - ◆ **None:** messages may arrive or may not arrive at a receiver
  - ◆ **K-reliable:** at least k members of the group receive the message
  - ◆ **Atomic/reliable:** all members or none of them receive the message
- Message ordering
  - ◆ **None:** messages arrive in arbitrary order at a receiver
  - ◆ **FIFO order:** messages arrive in the order sent by the sender
  - ◆ **Causal order:** causality of messages is reflected in the order of arrival
    - If a member of the group receives a message A and then sends a message B to the group, each group member will first receive A and then message B.
  - ◆ **Total order:** as causal order, but additionally not causally dependent messages arrive in the same order at each receiver

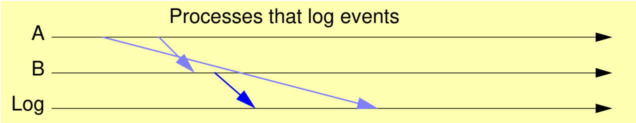
9 Group Communication (5)

- Examples for different message ordering



D.6 Selected Problems of Distributed Systems

- Causality
  - ◆ Simple message passing may violate causality (Log file example)



Log entries are not causally ordered

- Synchronization of processes
  - ◆ Semaphores and monitors depend on coherent shared memory
  - ◆ No shared memory on multicomputer systems
- Synchronization of clocks
  - ◆ System clocks are never exactly synchronized in distributed systems

D.6 Selected Problems of Distributed Systems (2)

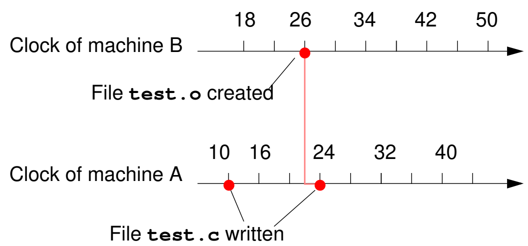
- Example: UNIX *make* command

Makefile

```
test.o: test.c

test: test.o
```

- ◆ Editor runs on machine A
- ◆ Compiler runs on machine B



➜ *Make* command will not notice necessary update!!

1 Logical Clocks

- Usually the precise absolute time is not necessary
  - ◆ We only need to know when one event causally depends on another
  - ◆ $a \rightarrow b$ is read "b is causally dependent on a"
  - ◆ If $a \rightarrow b$ and $b \rightarrow c$ then $a \rightarrow c$ (transitivity)
  - ◆ If neither $a \rightarrow b$ nor $b \rightarrow a$ is true then a and b are said to be **concurrent**
- Clock condition:
  - ◆ If an event b causally depends on an event a then timestamp of a must be less than the timestamp of b
  - ◆ $a \rightarrow b \;\Rightarrow\; T(a) < T(b)$
- Algorithm of Lamport (1978)
  - ◆ Messages as the only means for communication
  - ◆ Fulfills clock condition

1 Logical Clocks (2)

- Example

A	B	C
0	0	0
6	8	10
12	16	20
18	24	30
24	32	40
30	40	50
36	48	60
42	56	70
48	64	80
54	72	90
60	80	100

without logical clocks

A	B	C
0	0	0
6	8	10
12	16	20
18	24	30
24	32	40
30	40	50
36	48	60
42	61	70
48	69	80
70	77	90
76	85	100

with logical clocks

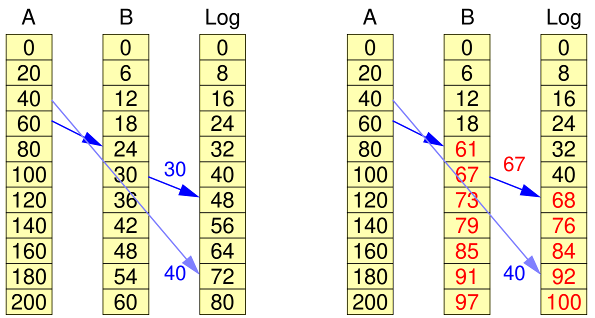
- ◆ Send event happens before arrival: send time must be less than arrival time!
- ◆ Solution: adjust local clock

1 Logical Clocks (3)

- Lamport's algorithm
  - Each process has its own logical clock (a counter LC that is used for timestamping of events)
  - Logical clock ticks for each local event
    - *Local event:* LC := LC + 1
    - *Send event:* LC := LC + 1; send(message, LC)
    - *Receive event:* receive(message, LC_S); LC := max(LC, LC_S) + 1
  - Fulfills clock condition
  - Reverse clock condition is **not** fulfilled!
    - $T(a) < T(b) \not\Rightarrow a \rightarrow b$

1 Logical Clocks (4)

- How does it help?
  - Logging processes: timestamp log messages with local clock

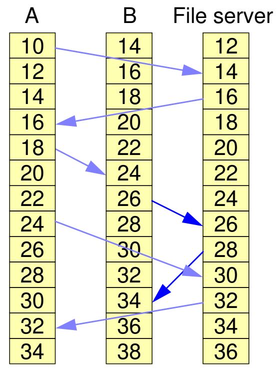


without logical clocks   with logical clocks

  - Logical clocks help to figure out the order of the log entries that reflects causality

1 Logical Clocks (5)

- Does it help for the "make" example?



A: write `test.c` (timestamp 10)

FS: `test.c` written

A: make starts compiler

B: write `test.o` (timestamp 26)

A: write `test.c` (timestamp 24)

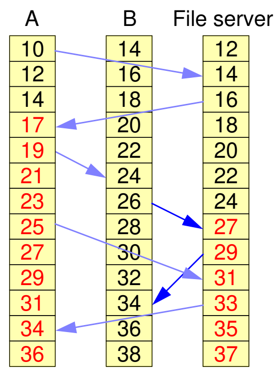
FS: `test.o` written

FS: `test.c` written

without logical clocks

1 Logical Clocks (6)

- Does it help for the "make" example?



A: write `test.c` (timestamp 10)

FS: `test.c` written

A: make starts compiler

B: write `test.o` (timestamp 26)

A: write `test.c` (timestamp 25)

FS: `test.o` written

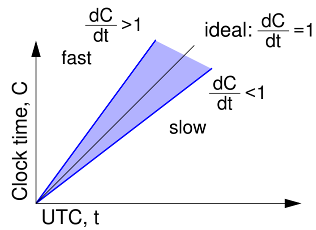
FS: `test.c` written

with logical clocks

  - NO!!

2 Clock Synchronization

- Local clocks are realized in software
  - ◆ Time chip signals interrupt that counts clock ticks
  - ◆ Local clock has a drift to UTC (Universal Coordinated Time)



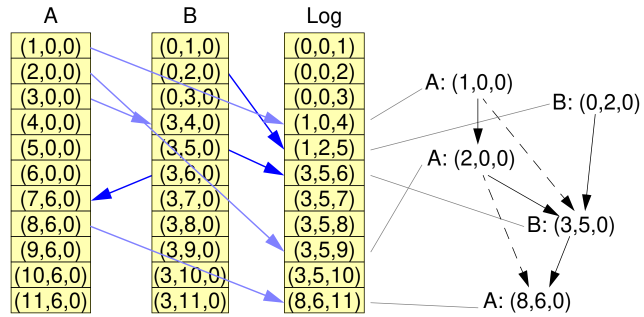
  - ◆ Synchronize local clocks to minimize drift to UTC
  - ◆ Sources: DCF77, GEOS, GPS, Atomic clock

3 Vector Time

- Sometimes we would like to know whether two events are causally dependent by looking at their timestamps
  - ◆ Corresponds to reverse clock condition
  - ◆ Impossible to derive with logical clocks
- Vector time introduced by Mattern (1989)
  - ◆ Each process i of k processes maintains a clock vector V_i of k clocks
  - ◆ Local event: $V_i[i] := V_i[i] + 1$
  - ◆ Send event : $V_i[i] := V_i[i] + 1$; send(message, V_i)
  - ◆ Receive event: $V_i[i] := V_i[i] + 1$; receive(message, V_S);
    $\forall j : V_i[j] := \max(V_i[j], V_S[j])$
  - ◆ Comparing two time vectors:
    - $a \le b : \Leftrightarrow \forall i : a[i] \le b[i]$
    - $a < b : \Leftrightarrow (a \le b) \wedge (a \ne b)$
    - $a \,||\, b : \Leftrightarrow \neg (a < b) \wedge \neg (b < a)$

3 Vector Time (2)

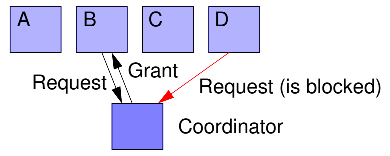
- Example: Logging Processes



  - ◆ Clocks start with concurrent timestamps
  - ◆ From the log we can identify causality of all logged events

4 Mutual Exclusion

- Semaphore needs coherent shared memory
  - ◆ Multicomputers cannot use a semaphore
- Centralized semaphore server and request-reply interaction
  - ◆ Centralized component (coordinator) acts like a semaphore
  - ◆ Every process has to contact the coordinator to get access to a critical region



  - ◆ Process B sends a release message to the coordinator after leaving the critical region
  - ◆ Single point of failure

4 Mutual Exclusion (2)

- Distributed algorithm
  - ◆ Lamport (1978)
  - ◆ Improved by Ricart and Agrawala (1981)
- Algorithm by Ricart and Agrawala
  - ◆ Total ordering of events
    - Lamport's logical clock value plus process ID **`(time, pid)`**
    - The tuple makes timestamps of different events different and comparable (if time is equal process ID of different events is not)
  - ◆ Group of processes that may enter a critical region
  - ◆ Process that wants to enter the region has to send a message to all others:
    - **`group_send( LC, pid )`**
    - Send must be reliable
    - Process waits until all other group member grant permission to enter the critical region

4 Mutual Exclusion (3)

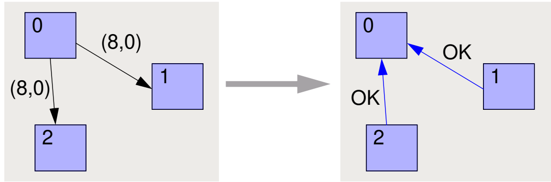
- ◆ If a process receives a message it does the following:
  - The receiver is not in the critical region and does not want to enter it:
    `send( OK )` to the original sender
  - The receiver is in the region:
    the message is enqueued
  - The receiver is waiting for entering the critical region:
    The receiver compares the timestamps of the incoming message with the timestamp of its own request message

    The own timestamp is lower:
    the message is enqueued

    The own timestamp is higher:
    `send( OK )` to the original sender
- ◆ After leaving a critical region a process sends back an **`OK`** for all enqueued request messages and deletes those messages

4 Mutual Exclusion (3)

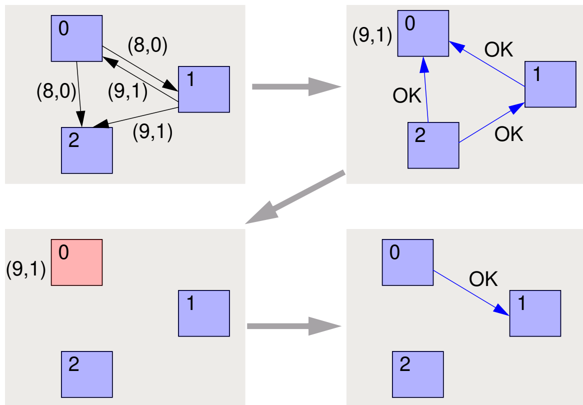
- No conflict: it clearly works



- ◆ The sender immediately gets OKs
- ◆ No further messages are sent or enqueued

4 Mutual Exclusion (4)

- Two processes want to enter the critical region at the same time



- ◆ The process with the lowest timestamp will win

4 Mutual Exclusion (5)

- Is it really better?
  - n points of failures
  - 2(n – 1) messages
  - Group membership must be known to all other processes
- Hardly better than the centralized version
  - Shows that it is possible to solve the problem by a distributed algorithm
  - Good example for distributed algorithms

5 Election Algorithms

- Problem
  - Find out a (new) coordinator, initiator, sequencer, or something similar
  - After the run of the algorithm
    - one group member should be the coordinator,
    - all other group member should know who was elected.
  - Multiple processes may start the election, but only one process will be elected.

6 Deadlock Detection

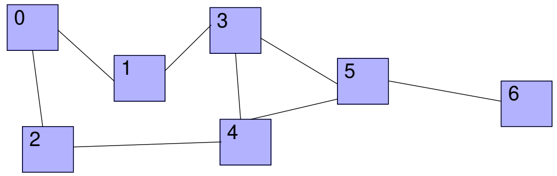
- Problem
  - Find out whether some processes are involved in a deadlock
  - Traversing the distributed dependency graph

7 Distributed Garbage Collection

- Problem
  - Find out data object that are not referenced any more
  - Traversing the distributed reference graph

8 Echo Algorithms

- Problem
  - Distributed information to all of not fully interconnected processes and compute a function (e.g. maximum of the output of all processes)



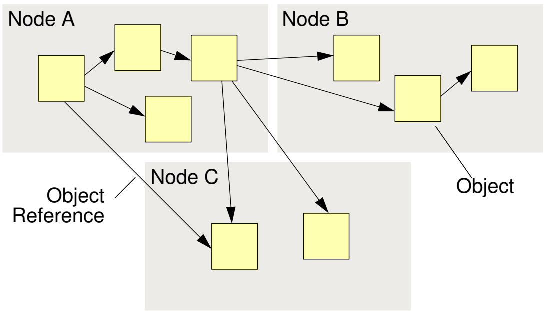
D.7 Object-Based Distributed Systems

- So far: processes
  - Processes & message passing
  - Processes & remote procedure calls
- Object-based programming
  - Objects
  - Classes
  - Methods, method invocation
  - Inheritance (object-oriented programming)

★ Systems that are distributed and object-based

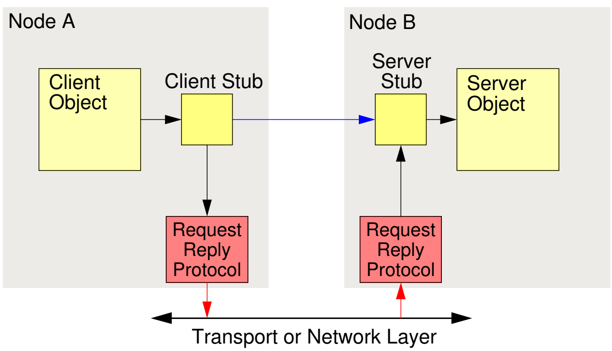
1 Holistic Approach

- Objects as distributable entities
  - Objects are distributed on several nodes and never split
  - Objects communicate with each other
  - Remote method invocation



1 Holistic Approach (2)

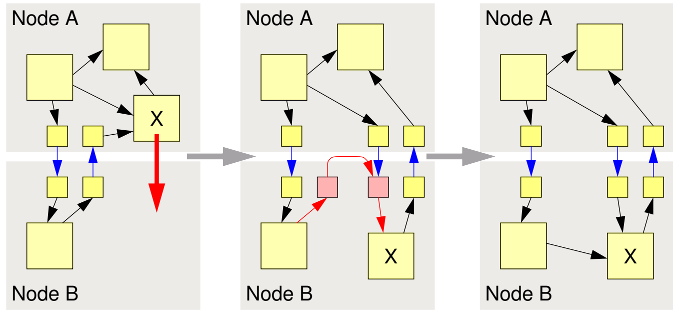
- Implementing remote method invocation
  - Stub objects similar to stub procedures



- Client-stub object represents server object at client's node

1 Holistic Approach (3)

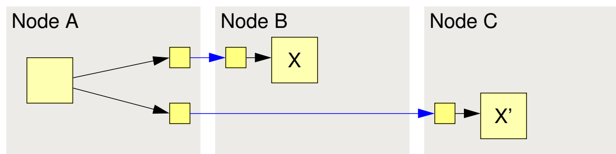
- Object mobility
  - Objects may migrate from one node to the other



  - Stubs have to be created for all references of the moved object
  - Local stub pairs can be abbreviated

1 Holistic Approach (4)

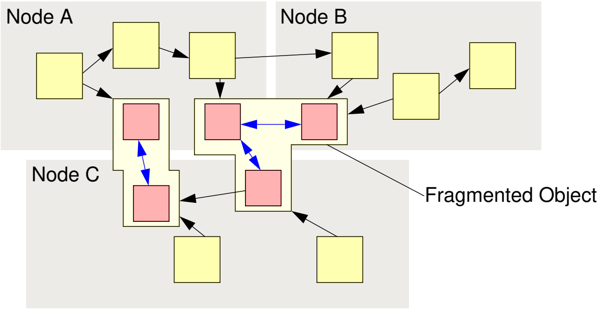
- Disadvantages
  - No transparent replication as object is a centralized entity



  - In general:
    Quality-of-service requirements often need object code at the client side!
    - Replication
    - Caching
    - Bandwidth reservation
    - etc.

2 Fragmented-Object Approach

- Distributed objects consist of fragments that can be spread over multiple nodes
  - Fragments communicate with each other
  - Method invocation is always done locally (local fragment is needed)



2 Fragmented-Object Approach (2)

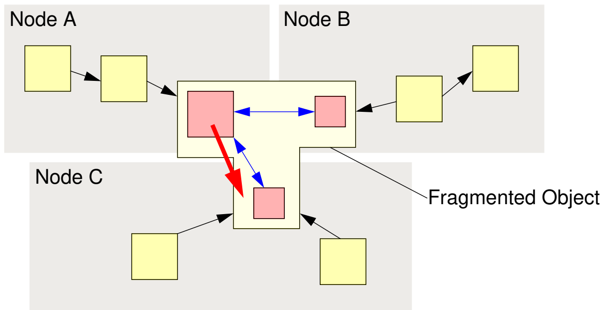
- Advantages
  - More general; includes the centralized object approach
    - one fragment is the main object
    - other fragments are stubs
  - Arbitrary communication between fragments
    - group communication for fragments replicating the object's state
    - real-time or transactional communication
    - communication with the object is always local
  - "Intelligent stubs"
    - local fragment can replicate or cache data of the object
    - local fragment can compute methods that do need little of the object's data

2 Fragmented-Object Approach (3)

- Disadvantages
  - Programmer has to build up the object-internal communication by his own
    - tools and libraries may help (e.g., stub fragment generator)
    - special name services may be needed
  - System does not know about stubs
    - Somehow, the system has to load the fragment code from somewhere whereas it otherwise only has to generate a stub.

2 Fragmented-Object Approach (4)

- Object mobility
  - Mobility is relative because the object is always accessed via a local fragment
  - Fragments may be mobile: fragments need to be replaced by one another



2 Fragmented-Object Approach (5)

- Example:
  - A new main fragment is built up at the side of stub fragment, takes over the essential data from the old main fragment, and replaces the stub.
  - The old main fragment is replaced by a new stub fragment